

Evaluation of the Dehydration Characteristics of Ginger (*Zingiber Officinale*) Root Slices Using Refractance Window Drying Technology

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Abstract— This study investigates the drying characteristics of ginger (*zingiber officinale*) root slices using the Refractance Window™ drying technology. A laboratory-scale dryer was constructed by modifying a water bath. 3 mm thick ginger root slices were dried on the transparent Mylar PET plastic film that covered the bath, and the variation of the moisture content of the slices with time was determined as the drying progressed. A water temperature of 60 °C was maintained beneath the plastic film. Various drying kinetic data curves are plotted from the drying data and the thin layer model that best fits the drying data was determined. Observations indicated that the ginger root slices dried to a moisture content of 0.1g H₂O/g solid on a dry basis in about 210 minutes. The regression analysis results showed that the Haghi and Ghanadzadeh thin layer model best describes the drying data for 3 mm sized slices with the coefficient of determination (R^2) value of 0.9985. An effective moisture diffusivity of $8.99 \times 10^{-8} \text{ m}^2/\text{s}$ was observed for the ginger root slices.

Keywords— Ginger, Refractance Window™ Drying, Thin Layer Drying Models.

1. INTRODUCTION

Ginger, (*Zingiber officinale roscoe*, *Zingiberaceae*) is a well-known plant grown in India, China, South East Asia, West Indies, Mexico and warm climates of the world (Bhavna and Upadhyaya, 2016); it has many uses in the medicinal, cosmetic, food and beverage industries (Abdel-Aziz *et al.*, 2005; Abdel-Aziz *et al.*, 2006; Alzoreky, 2003; Parthasarathy *et al.*, 2008; Capuzzo *et al.*, 2013). Clearly, from the many uses of ginger, a post-harvest preservation and storage method for ginger is important. Drying is an important post-harvest ginger preservation operation because it is a simple method for quick conservation of the qualities of the root; it is also a method to reduce bulk weight of ginger to facilitate ease of transportation (Kiaya, 2014). While natural sun drying is often a chosen method of dehydrating ginger, it should only be considered for drying of small quantities.

Loha *et al.* (2012) evaluated the drying characteristics of sliced ginger (*Zingiber officinale*) in a forced air convective cabinet dryer. In the study, it was concluded that the Midilli *et al.* thin-layer drying model, (Midilli *et al.*, 2012), best represented the drying kinetics of sliced ginger. Afolabi *et al.* (2014) studied the influence of thin layer drying behaviour of ginger root slices in a laboratory dryer for ginger root slices of 5 mm, 10 mm and 15 mm thicknesses using heated ambient air at temperatures from 40 to 70 °C and an air velocity of 1.5 m/s. The results indicated that an increase in the drying air temperature and the thickness of the slices both caused shorter drying times.

The Refractance Window™ drying technique is a new method of drying. The technology was developed by MCD Technologies Inc., Tacoma, WA, USA. The technology had been used to convert liquid foods and related biomaterial into flakes, powders, and sheets (Nindo and Tang, 2007). Studies indicated the purees or juices prepared from fruits, vegetables, or herbs dried within 3 – 5 minutes. Akinola *et al.* (2014) dried 1 mm, 2 mm and 3 mm sized shreds of red onions. The Haghi and Ghanadzadeh thin layer drying model best represented the drying kinetics of shredded onions. The

purpose of this study is to examine the drying kinetics of ginger rhizome slices using the Refractance Window™ drying technique and determine the thin layer drying model that characterizes the drying kinetics.

2. METHODS AND MATERIAL

2.1 The Equipment

The Refractance Window™ type dryer used in this study is shown in Fig. 1. The dryer is constructed by modifying an electrically heated water bath that has a temperature controller. A transparent plastics film replaces the bath's cover and the film fastened in place with metal angle brackets. The brackets were placed so that the lower side of the plastic film is always in contact with the water in the bath. The plastic film has a thickness of 0.15 mm and a refractive index similar to that of water. Parts of the equipment consist of a Refractance Window, Type K thermocouples used to measure the temperature of the water bath, top of the plastic film and the temperature of a ginger root slice. The thermocouples are connected to a Measurement Computing's USB-5100 Series Multi-Channel data logger; the data-logger connects to the Personal Computer (PC). A current of air was maintained above the Refractance Window using a fan; this was to ensure that the vapour above the window did not inhibit the drying process.

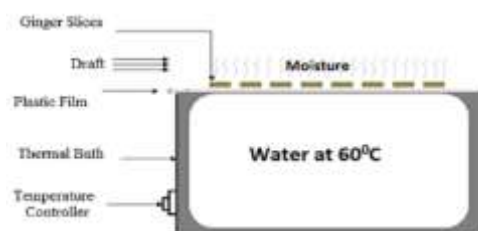


Fig. 1: Set up of the Apparatus Used

2.2 Preparing the Ginger Root Slices

Ginger rhizomes tubers obtained from a local market were used in this study. The ginger tubers were washed, peeled and cut into 3 mm thick slices using a Mandolin type slicer. The slices are then dried on the plastic film on the dryer. The thickness of the ginger root slices was measured with a digital Vernier caliper

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2.3 The Experimental Process

The water in the bath is heated to a temperature of 60°C and this temperature is maintained throughout the experiment. With the plastic film secured in place, ginger root slices are placed on the plastic film to dry. At specific times, as the experiment progresses, some ginger root slices are removed and the moisture content determined using an MB45 OHAUS Moisture Analyser (OHAUS, 2011). The drying process is stopped when the moisture content of the sample is about 5% (w.b). The drying experiments are repeated three times for each drying period and the average moisture content values for each period taken.

2.4 Moisture Content and Moisture Ratio

The moisture content was measured on a wet basis, however, in this study, moisture content is used on a dry basis. The method of converting moisture content on a wet basis to dry basis is detailed in literature (Singh and Heldman, 2017). In this study, the equilibrium moisture content is small, therefore, the moisture ratio (MR) was determined according to 'equation (1)' (Doymaz, 2007; Goyal et al., 2007).

$$MR = MC_t/MC_i \quad (1)$$

where

MC_t is the moisture content of ginger after drying for time *t* and

MC_i is the initial moisture content of fresh ginger in kg-water/kg-solids.

2.5 Processing Experimental Data

The experimental data obtained from the experiments will be fitted to the thin layer drying models listed in Table 1.

Table 1. Thin Layer Drying Models

S/N	Model
1	MR = a.exp (-b.t ^c) + d.t ² + e.t + f Haghi and Ghanadzadeh (2005) Model
2	MR = a.exp (-k.t ⁿ) + b.t Midilli et al. (2002) Model
3	MR =exp (-k.t ⁿ) Page (1949) Model
4	MR =a.exp (-k.t) + c Logarithmic Model (Togrul and Pehlivan, 2003)
5	MR = exp (-k.t) Newton Model (Ayensu, 1997)

Regression analysis was performed to determine the thin layer drying models that best fit the drying data. The parametric coefficients of each model are determined using Matlab, a well-known mathematical software package. The model is chosen to be the best fit if the value of the coefficient of determination (*R*²) is closest to unity, and mean-bias-error (MBE), and root-mean-square-error (RMSE) values are minimum (Akpınar, 2010; Tunde-Akintunde and Afon, 2010). The equations used to determine *R*², MBE, and RMSE are discussed in many statistical textbooks (Ogunnaike, 2011), and have been used in a number of thin layer drying modelling articles (Togrul and Pehlivan, 2003; Tunde-Akintunde and Afon, 2010; Akinola et al., 2014).

2.6 Effective Moisture Diffusivity Determination

The Effective moisture diffusivity (*D*_{eff}) was determined using Fick's second equation of diffusion (Crank, 1975). Assumptions detailed by Jena and Das (2007) indicated that the Fick's second law in the form presented in 'equation (2)' is appropriate.

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (2)$$

where,

MR is the moisture ratio, *D*_{eff} (m²s⁻¹) is the effective moisture diffusivity, *L* (m) is the sample dimension.

The assumptions are that the slice is considered to be of constant moisture diffusivity, infinite slab geometry, and a uniform initial moisture distribution. A plot of -ln(MR) against drying time gives a slope *k_d*, from which *D*_{eff} can be obtained according to the 'equation (3)'.

$$k_d = \frac{\pi^2 D_{eff}}{4L^2} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Thin Layer Models

The experimental data of the drying process were fitted into 5 thin layer mathematical drying models frequently used in food drying (see Table 1). The drying model that best fitted the experimental data is determined to be the Haghi and Ghanadzadeh (2005) thin layer drying model. The criteria used was that the coefficient of determination (*R*²) value be closest to 1 and the MBE and RMSE value be closest to zero (Table 2). For the Haghi and Ghanadzadeh model *R*², MBE, and RMSE values are 0.9985, 0.0000, and 0.0124 respectively. Also, Table 3 presents each model's constants obtained by fitting the models used to fit the experimental data.

Further validation that the Haghi and Ghanadzadeh thin-layer drying model best fits the drying kinetics was done by correlating the values of Experimental Moisture Content (EMC) vs. Predicted Moisture Content (PMC). The linear relationship obtained is presented in equation (4) was obtained.

$$PMC = 0.999EMC + 0.0061 \quad (4)$$

The line had a slope of 0.999, and *R*² values of 0.9994 respectively. Clearly, the experimentally determined and predicted moisture contents of the 3.0 mm thick ginger root slices do not vary significantly.

3.2 The Dehydration curves

Plots of the experimental moisture content vs. time, the predicted moisture content vs. time, and the predicted drying rate, for the ginger root slices are shown in Fig. 2. The left vertical axis is for the drying curves while the right vertical axis is for the drying rate curve. The predicted plots are based on the Haghi and Ghanadzadeh model. The plots indicate that ginger root

slices with an initial moisture content of 6.30 g-water/g-solid dried on a Refractance Window™ type dryer to below 0.10 g-water/g-solid (dry basis) within 210 minutes. This drying time is considerably shorter than the 5 – 23 hours experienced when dehydrating roots, fruits and vegetables using an Excalibur Dehydrator by Discount Juicers (1998).

Also observed on the plot, the drying rate initially increases, reaches a peak value and then falls. This observation is consistent with the different stages of drying presented by Kemp et al. (2001), Fyhr and Kemp (1998) and Traub (2002a, 2002b). Increasing drying rate

occurs in the initial-rate period. The drying rate peaks after about 35 minutes with a value of 0.0857 g-water/g-solid/min. As the constant drying rate period is for all intents absent, this at this critical moisture content, after this, the drying rate falls. As shown in Fig. 2, the falling rate drying period has two stages. The first stage is the unsaturated drying falling rate period in which the surface moisture is being removed. The period occurs from the 36th to the 110th minute. At about the 110th minute, the drying process enters the saturated drying falling rate period, in which the plane of evaporation moves through the drying material, and the drying rate falls further.

Table 2. Coefficient Obtained by Fitting Data to the Various Thin Layer Models for Ginger

No.	Model Name	R ²	MBE	RMSE
1	Haghi and Ghanadzadeh	0.9985	0.0000	0.0124
2	Midilli et al.	0.9974	-0.0011	0.0162
3	Page	0.9963	-0.0089	0.0193
4	Logarithmic	0.9812	0.0000	0.0434
5	Newton	0.9778	0.0019	0.0470

Table 3: Constant Obtained by Fitting Data to the Various Thin Layer Models for Ginger

No.	Model Name	Polymath Constants			
1	Haghi and Ghanadzadeh	a= 0.775953	b= 0.000589	f= 0.227672	
		c= 1.876987	d= 3.08E-06	e= -0.00165	
2	Midilli et al.	k= 0.001993	a= 1.007633	n= 1.518419	b= 5.60E-05
3	Page	k= 0.002142	n= 1.494521		
4	Logarithmic	a= 1.061432	k= 0.017186	c= -0.01454	
5	Newton	k= 0.017179			

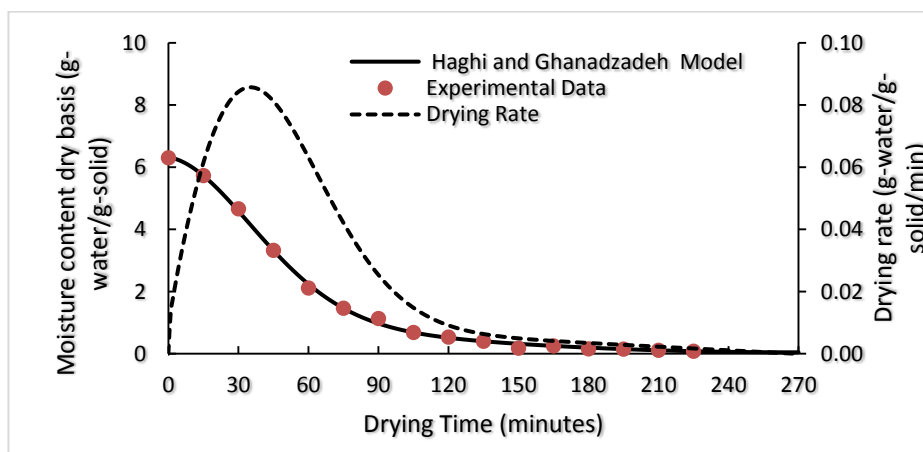


Fig. 2: Variation in Moisture content with time and the drying rate curve

3.4 Effective moisture diffusivity

A plot of $-\ln(MR)$ vs. drying time and the linear relationship is shown in Fig. 3. From the slope of the line, k_d , which equals to 0.0002466, the effective moisture

diffusivity, D_{eff} , value is obtained according to 'equation (3)'. An effective moisture diffusivity value of $8.99 \times 10^{-8} \text{ m}^2\text{s}^{-1}$ is obtained as the for 3 mm thick ginger root slices.

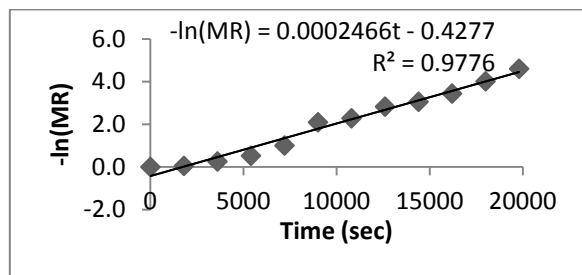


Fig. 3: $-\ln(MR)$ vs time plot - Estimation of Moisture Diffusivity Coefficient

4. CONCLUSION

The following conclusions can be made of 3 mm thick ginger root slices with an initial moisture content of about 6.30 g-water/g-solid on a dry basis dried using a laboratory Refractance Window™ dryer. The 3 mm ginger root slices were dried to a moisture content of below 10%, dry basis, within 210 minutes. The Haghi and Ghanadzadeh thin layer model best fits the drying kinetics with a coefficient of determination (R^2) value of 0.9985. The effective moisture diffusivity value of $8.99 \times 10^{-8} \text{ m}^2\text{s}^{-1}$ was determined for the 3 mm thick ginger root slices.

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